FLOW GAS TRANSDUCER IN BASIS OF A HOT WIRE WITH A NIQUEL-TITANIUM ALLOY ITS FLOW CALIBRATION SYSTEM

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Abstract: **In our Latinamerican countries, people have rarely developed about medical control systems based in sensors (transducers) and actuator done in our enviroment. This has motivated the present work.**

In medical applications such as breathing systems the hot wire flow sensors are being used actually. Taking advantage of the sensor thermal convection, we can achieve a rapid operation using a smaller than 250 ms sampling time.

This study was made based in stuff such as Nicrom (100 um), Nickel-Titanium alloy (37 and 100 um) and Platinum (21 um), that use the "King´s Law" that relates Thermal Convection with Electrical Power; this law may detect flow changes through voltage changes when the temperature is constant; showing succesfully an alternative of flow sensing in any given conditions.

The flow calibration system used in this work is based in the principle of the RC discharge, using the constant compliance of a rigid water column, where the pressure gets a lineal shape with a pressure step source and a 450 us sampling time for this two signals: flow and pressure.

Key words: **Sensor, transducer, active transducer, compliance, volume flow, measurement, pressure.**

I. INTRODUCTION.

The equipment development is limited by the difficulty of manufacturing transducers and actuator appropriate to the requirements, although the other components as: microprocessors, operational amplifiers, etc are found with relative facility.

The low-cost flow transducers generally have a response time higher than 250ms, with sensibility decrease, in order of obtaining better characteristic is paid in some instances more than $500 for sensor, and more for data acquisition and flow sensor systems of good sensibility (1), (2), (3), (11).

In this context a prototype of flow transducer is developed with special characteristics, based on the measurement principle by means of hot wire that confers us greater properties due to the thermal convection, which requires now a smaller time to measure the flow gases variations and a smaller volume of material for the sensor.

OBJECTIVE: Development of a flow transducer prototype with rapid response gases and high precision, seeking to fulfil the medical norm ISO 9360 [10], with sensed between 1 and 100 Lpm y 5% of accuracy.

II. METHODOLOGY.

1. *THEOTERICAL FUNDAMENTALS.*

Volumetric flow:

The volumetric flow is defined as the pass of the volume in the time.

For gases the volumetric flow depends directly the gases equation on Van Der Walls, for smaller pressures to 50 atm [8].

$$(P+\frac{an^2}{V^2})(V-nb)=nRT \qquad (1)$$

P: Gas Pressure.
V: Gas Volume.
R : Gases Constant (8,319 N-m/mol - K)
T: Gas Temperature.
n: Mol Number.

This equation for the oxygen presents the following values of a = 1,36 L^2 /atm/mol^2 and b = 0,0318 L/mol.

As we will handle low pressures (of a 1psi = 0,068 atm), we may consider this for the design in the ideal gas.

$$P.V = n\,R\,T$$

Thus, this flow is near to the ideal gas.

$$Q=\frac{dV}{dt}=\frac{d}{dt}\left(\frac{nRT}{P}\right) \qquad (2)$$

Mass Flow:

For the mass flow, is used the state equation of the ideal gas, resulting the mass flow:

$$\dot{m}=\frac{dm}{dt}=\frac{d}{dt}\left(\frac{P.PM}{RT}.U.A\right) \qquad (3)$$

U: Fluid speed.
A: Section of the flowed to measure.
PM: Gas Molecular weight average.

Theoretical fundamentals of the sensed with hot wire:

In stable state, the heat dissipation follows the King's Law [3]

$$I.V=K_{eff(U)}(T-T_a) \qquad (4)$$

Where:

I, V: Current and voltage.
T_a: Environmental temperature.
K_{eff}: Coefficient of heat transfer.
U: Fluid speed.

Upon having flow to laminate the K_{eff} will be:

$$K_{eff(U)}=K_o+K_1U^n \qquad (5)$$

Where

K_0 and K_1: Constants
n: Constant of the material

In constant temperature manner, being T the environmental temperature, equation 5 can follow the equation 4 to the form:

$$V^2=k_o+k_1U^n \qquad (6)$$

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25OCT2001	N/A	-

Title and Subtitle Flow Gas Transducer in Basis of a Hot Wire with a Niquel-Titanium Alloy its Flow Calibration System	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Grupo de Investigacion y Desarrollo de Equipos Medicosy Sistemas (GIDEMS) Pontificia Universidad Catolica del Peru Av Universitaria S/N - San Miguel, Peru	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
4

And if $k_1.U^n << k_0$ then:

$$V = A_2 + B_2 U^n \qquad (7)$$

V: Voltage measured in the material.

Of this expression the speed is related directly to the measured voltage, the different values of n that are extracted.

2. DEVELOPMENT OF THE TRANSDUCER.

Viability of the transducer:

It is proven the operation of the hot wire, for example, submitting a wire of cromel to a current higher than 0,5A and is blown on its, is measured a resistance variation with a voltage change, then it can be related this to the variations due to the flow and temperature; that is to say under certain conditions as compensating the temperature, we will be able to find flow as variable principal of this effect. They are avoided meaningful fluctuations upon increasing the sensor's temperature, and will impinge less on the King's Law (equation 4), by something which are sought metals that may have a temperature of fusion and high oxidation, and depending on the application can require to resist the environment, as the corrosion between other, furthermore it must be laminable and resistant to chemistry reactions.

Material (Type of wires)

The wires used in this study sensing, flow are: Nicrom, Nickel -Titanium alloy and Platinum.

Of these materials can be recaptured: The Platinum and the Nickel-Titanium alloy, by having good resistance with respect to the chemical and environmental agents as the acids and corrosion, so they are inert in the work conditions, with high fusion temperatures, and oxidation occurs on 540°C

The Nicrom or Cromel presented serious disadvantages in the tests, such as great response time and furthermore variable with the time, this hinders its use.

The study made is outlined by the Nickel– Titanium alloy, the one which shows good characteristic that make this sensor with its corresponding transducer circuit a very economic one; furthermore taking into account that there is no Nickel -Titanium alloy sensors developed until where we know, provides the first novelty of this investigation.

Development of the flow transducer.

The hot wire sensed method for hot wire was proven with material as: Nicrom, Platinum and Nickel-Titanium alloy, etc. At the moment the most used material is the Platinum, that it is inert at temperature decreases, has a resistance variation vs almost linear temperature (in less than 1%) and smaller response time to 20ms. To reduce costs has been employed this project is employed Nickel-Titanium alloy of 37um of diameter, to which is added a profit circuit that permits to increase the small variation at the sensor's output (of 20mV to 100mV), with a temperature circuit control that on the based of the readings amplification of a Wheastone's brigde to a Darlington maintains a stable temperature in the sensor temperature approximately 100°C, and other temperature to 300°C. This material is not used in the commercial sensors (1), (2), (3), (11).

Fig. 1 shows the system diagram block where the King's Law is implemented with a resistance circuit-constant temperature:

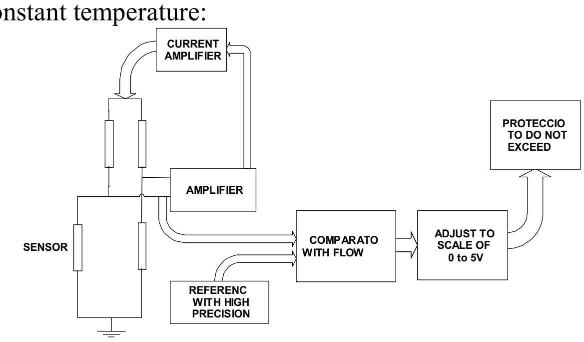

Fig. 1 Blocks diagram of the transducer circuit of the sensor Nickel – Titanium alloy

Used circuit:

Fig. 2 shows the circuits idea, using the power transistor BDX53C for feedback with current to keep the sensor in constant temperature. The electrical sign entry to an instrumentation amplifier (AD620), corresponding the other entry to a flow zero originating from the LT1021, regulatory of precision with 5mV of error.

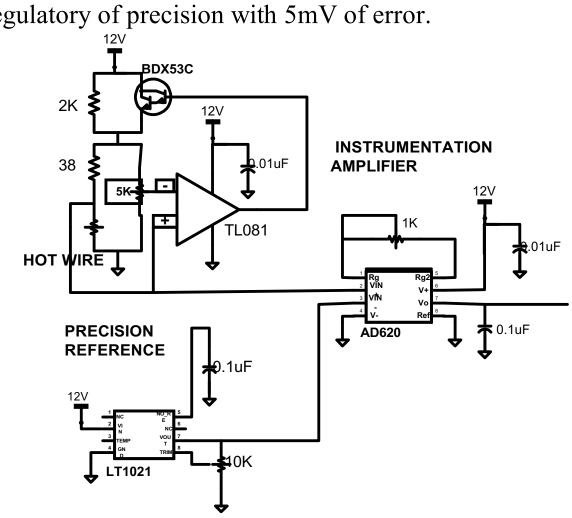

Fig. 2 Electrical diagram flow transducer.

Test with Platinum (Platinum 99.99% pure).

For a resistance of 7.5 ohm in cold with a diameter of 21 um (measured in the Corrosion Laboratory), it can be calculated through these data that the resistance to 350°C is of 20 ohm, the tests with this material were made in August of 1999, being proven a range of up to 200 LPM in 20 ms.

3. EXPERIMENTATION WITH SENSORS BASED ON NICROM AND NIQUEL-TITANIO ALLOY

Test with Cromel (Nickel Alloy and Chrome).

Tests with Cromel 38 (typical wire of clothes dryers) of 101.6 um (0.004"), with ambient resistance among 3,3 and 3,5 ohm, measuring until 30 LPM with response time of 100ms but with oxidation of the material that it a little while ago viable as flow sensor; however it showed the viability of the method of sensed with other material.

Test with Nickel –Titanium alloy.

The tests with Nickel-Titanium alloy of 37 um of diameter, threw a measured flow of up to 110 LPM with time response of 50ms, permitting to reduce costs, was used current between 30 and 200mA to prove different transducers.

Upon welding the material can be affected the structure of the same, by something which is compressed on the extremes of the wire for its mechanical subordination (Fig. 3) and thereinafter is fixed with weld.

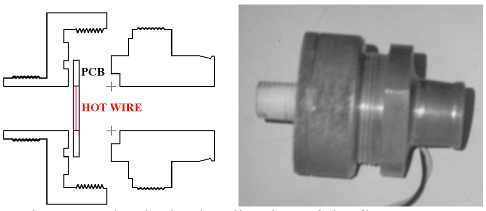

Fig. 3 Mechanical subordination of the flow sensor.

4. DEVELOPMENT OF THE CALIBRATION SYSTEM.

To obtain the parameters from this development and the future has been developed a flow calibration system such as is seen in the Fig. 4 consists of:

- Source of Pressure: CCECATO pump
- Pressure gauge to the entry.
- Proportional flow valve HERION 7037
- Pressure sensor MPX5010D of Motorola in the mouth of the column, with error of the 0,5%.

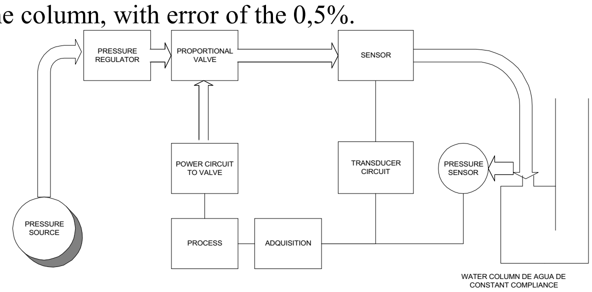

Fig. 4 Blocks graph of the calibration.

The calibration system uses the principle of the communicating glasses, the resistance model of the coarrugated pipes (that decreasing the turbulences) and the constant compliance. The compliance measures the pneumatic elasticity of an element, the expression that defines it is: $C = \frac{\Delta V}{\Delta P}$, which is constant for the column with water of the Fig. 4 (similar to a condenser of constant capacitance) according to the recently used system [5].

If the flow is constant, the pressure takes the form of ramp, such as is shown in the Fig. 5 due to the compliance constant of the water column, permitting to calibrate the readings in the flow gas transducer of Hot Wire of Nickel - Titanium alloy taking into account furthermore the various existing environmental temperatures, taking each sign each 450us, this was developed the year 2000

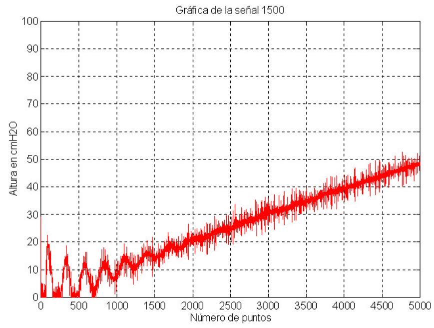

Fig. 5 Response in pressure ramp in the flow gauge

The compliance of the used column is of 37.5 cm^3/cmH_2O, and average resistance of 2 $cmH_2O/(cm^3/s)$ in the electrical model shown in the Fig. 6 (where is not considered the inertance, by considering little time and consequently a few volume variation) of the plant, is arrived theoretically to a precision of 0.3% in 0,5s, something which permits to evaluate 1000 calibration points, however are taken 5000 and the program evaluates 1000 better points in pressure, to evaluate the flow.

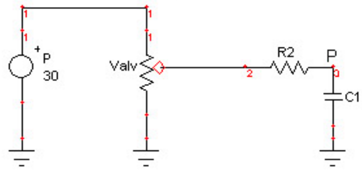

Fig. 6 Electrical model of the calibration plant

It is considered the compressibility of the flowed with the pressure measure, taking into account the absolute pressure. The data are taken by adquisition of a serial ADC of 12 bits (TLC2543) through parallel port, that it is handled by a program made in Language C and defendant in the MATLAB.

Fig. 7 Calibration System and sensed of flow used in test stages

III. RESULTS.

- It was obtained a sensor of hot wire to different current (between 30 and 200mA), of those which are used 2 transducers that sustain current between 40 and 45 mA and between 90 and 100 mA

- It has a temperature control with establishment time of 1 min and precision of the 2%
- The calibration system shown in the Fig. 7, , considering the error by compresibilidty, of sensed of pressure and of managing with the PC has a maximum error of the 1% in a time of 0,5 s of analysis.

The sensor of the Fig. 8 result of this work has the following characteristic:

- Measure range: 0.1 to 24 LPM
- Response time: 220ms
- Out Voltage: 0 up to 5 VDC
- Measure Sensibility: 100 mL/min
- n = 1/2 with respect deviation to the theoretical 3,5% (equation 7).
- Disadvantage: Very sensitive to variation of the temperature of the gas (0,5°C diverts a 5%).
- Error of the calibration system: 0,9% of the value.

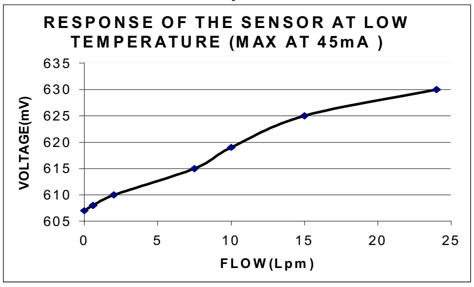

Fig. 8 Flow sensor at low temperature.

The transducer of the Fig. 9 result of this work has the following characteristic:

- Measure range: 1 to 110 LPM
- Response time: 50ms
- Out Voltage: 0 up to 5 VDC
- Measure Sensibility: 1 L/min
- n = 1/2 with respect deviation to the theoretical 1,5% (equation 7).
- Error of the calibration system: 1% of the value.

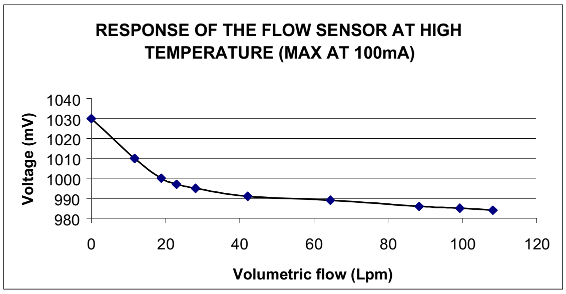

Fig. 9 Flow sensor at low temperature

IV. DISCUSSION.

These lasts Ilustrations (8 and 9) use a change in the inflection of the Resistance curve vs Current, for the different transducers implement with this material.

It can be used the in medical equipment sensed system, being the current goal a Pulmonar Ventilator, with response time less than 100 ms, to control of inspiratory flow.

In this type of instruments time response can not be reduced less than 10ms, limiting the frequencies to 100Hz [8], however response time will be reduced, using the advance in phase of the sign.

It is also possible to measure the average direction of the speed taking into account the arriving speed field with a different angle of 90° to the mentioned wire, that seeks upon turning the probe and when the angle changes to some 50°, the variation shown is smaller [7], but it is not quantified in this study.

The Platinum sensor follows the equation 6 and the Niquel-Titanium alloy sensor follows the equation 7.

Objectives of response time less than 250 ms, precision of 1% and flow sensor with resistence to work (like temperature of flow and pressure less than 50 Psi) have been achieved with hot wire, and accuracy of 5% has not been probed.

V. CONCLUSIONS.

Even though the flow transducer has been fulfilled the norm ISO 9360 largely, yet lack to happen the evaluation period in time and probed accuracy of 5%.

The Niquel-Titanium alloy hot wire sensor is possible to build with this material, no used by the fabricants (1), (2), (3), (11) who uses Platinum.

The flow sensor development has shown viability for high and low flows, with a useful calibration system for other sensors as Venturi and Neumotach.

ACKNOWLEDGEMENT.

To my friends of the GIDEMS by their friendship and comprehension, especially to Alejandro and Bruno by their help and support.

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